Crystal Calorimeter Development for EIC based on PbWO4

New Proposal

Project Name: Crystal Calorimeter Development for EIC based on PbWO4

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EIC endcap calorimeter

- A high resolution calorimeter has been specified in the EIC White Paper. The calorimeter should provide:
  - angular resolution to at least 1 degree to distinguish between clusters,
  - have an energy resolution of ~few %/sqrt(E) for measurements of the cluster energy,
  - and withstand radiation to at least 1 degree with respect to the beamline

- *At small angles*, where most scattered electrons end up, a high resolution calorimeter is important regardless of tracking (resolution of Bdl/tracker blows up in that region) -> Inner end cap calorimeter

- *At larger angles* another technology could be used

- In the absence of a threshold e/π Cherenkov a high resolution calorimeter would also be important for PID

Crystal calorimeters

- Crystal calorimeters have been used in NP and HEP for their high resolution and detection efficiency

- Good candidate for EIC “inner” end cap calorimeter solution: **PbWO4**

- PbWO4 is used in many existing and future experiments: CMS, JLab/HyCal, PANDA, JLab 12 GeV, NPS

- The critical aspect for crystal quality and so resolution is combination of light output and radiation hardness, which depend strongly on manufacturing process

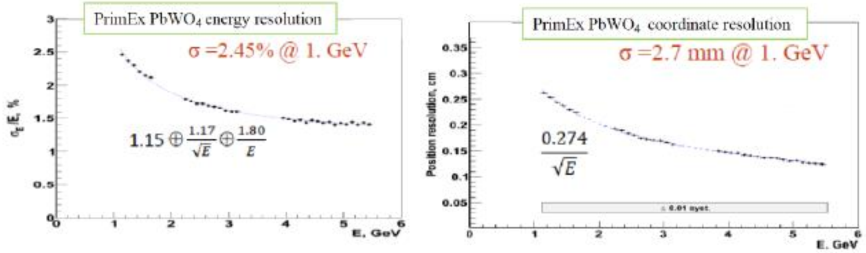


Figure 1. The energy and position resolutions of $PbWO_4$ crystals from the HYCAL at JLAB [5].

Parameter	Lead Tungsten (PbWO4)	Lead Fluoride (PbF2)	Bismuth Germanate (BGO)	Luterium-Yttriu (LSO/LYSO)
Density (g/cm³)	8.28	7.66-7.77	7.13	7.2-7.4
Rad. length (cm)	0.89	0.93-0.95	1.10-1.12	1.16
Refractive index	2.20	1.82	2.15	1.82
Emission peak (nm)	420	~310, ~280	480	420
Moliere radius (cm)	2.19	2.22	2.15	2.07
Radiation type	Scint. (~13% Č)	Pure Čer.	Scint. (~1.6% Č)	Scintillation
Timing property τ (ns, %)	(73%); 14 (23%); 110 (4%)	Fast, <30	300	40-50
Effective Z	73	77	83	65
Hydroscopicity	No	No	No	No
Interact. Length (cm)	~20.7	~21	~22.7	~20.9
Rad, hardness (krad)	~20-50	~50	~1,000	>1,000
Light yield LY (photon/MeV)	~140-200	~2-6	~5,000-10,000	~5,000-30,000
d(LY)/dT (%/°C)	-2.0-2.5	No	-0.9	-0.2
Critical energy (MeV)	~9.6	8.6-9.0	7.0	9.6

Table 1: Comparison of the properties of various dense crystals

Worldwide requirements on $PbWO_4$

Parameter	NPS Ideal	NPS Acceptable	CMS	PANDA
Light yield (pe/MeV)	10-15	5-6	<30	15-16
Transmission (20cm) (%) at λ~420 nm	>60%	~40	>8	>60%
Uniformity of optical properties (%)	~10	<20	>55	~10
Radiation hardness LY loss(%) for 1.5 Krad at dose rate 15rad/h	5	~10	<10	<10
Uniformity rad. Degradation at the same dose (20%)	~20	<30	<6	
Tolerance in dimensions (um)	+/- 50	+/- 100	~10	~10
Timing property (ns, %)	30-50, 90%		5-10	5-10

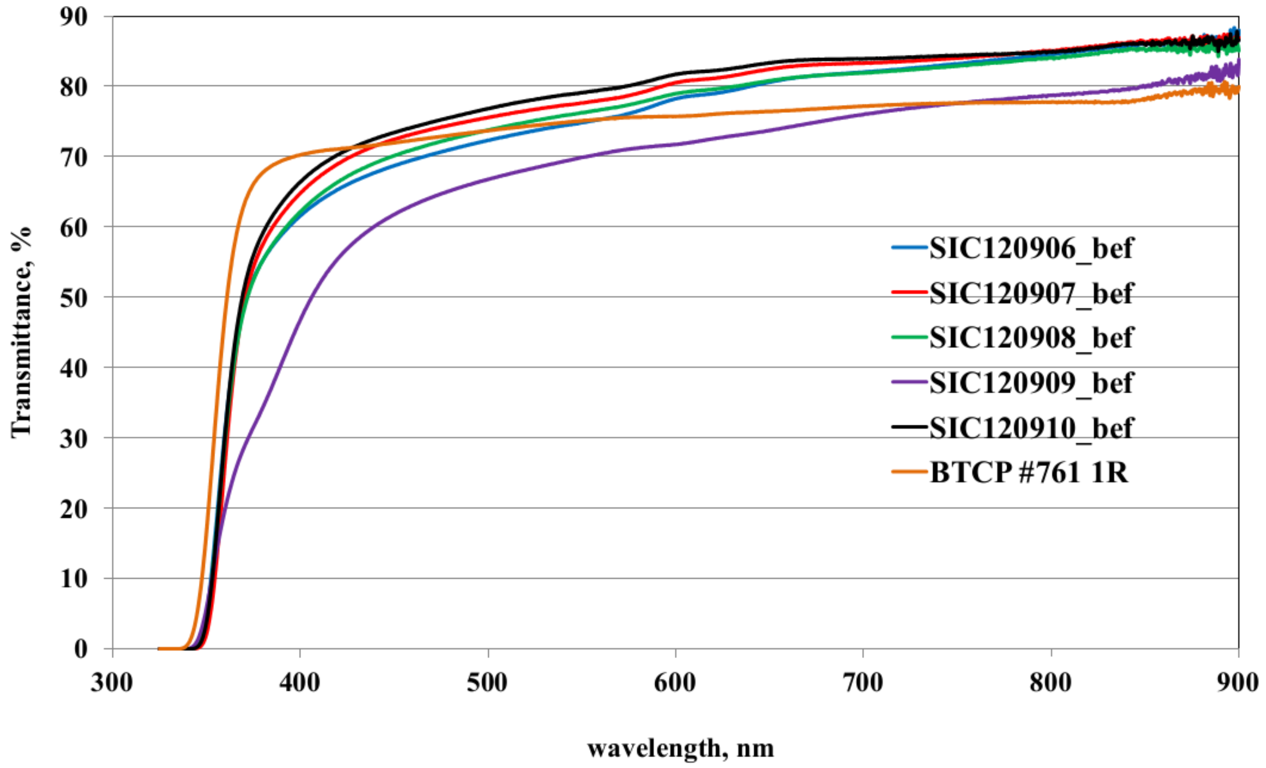
Availability of $PbWO_4$ Worldwide

- BTCP (Russia) – out of business
  - Produced most of the CMS crystals using Czochralski crystal growing method

- SICCAS (China) – produced crystals for CMS, and more recently PANDA, JLab
  - Uses the Bridgman crystal growing method

Performance of recent PbWO4 from SICCAS

- Tests results of recent SICCAS produced crystals for PANDA and Jlab compared to BTCP crystal



- Not clear if PbWO4 crystals of high quality are currently available

Goal of proposed R&D

- Identify what would need to be done to be able to build a $PbWO_4$-based inner end cap calorimeter exploring the limits of $PbWO_4$ crystal quality
  - Close collaboration with CRYTUR/Czech Republic.
  - Collaboration with PANDA, JLAB provides mutual benefits

- Simulation Studies
  - Radiation dose estimate
- Evaluation of crystal quality
  - Gamma ray radiation studies
  - Hadron damage studies
  - Neutron damage studies

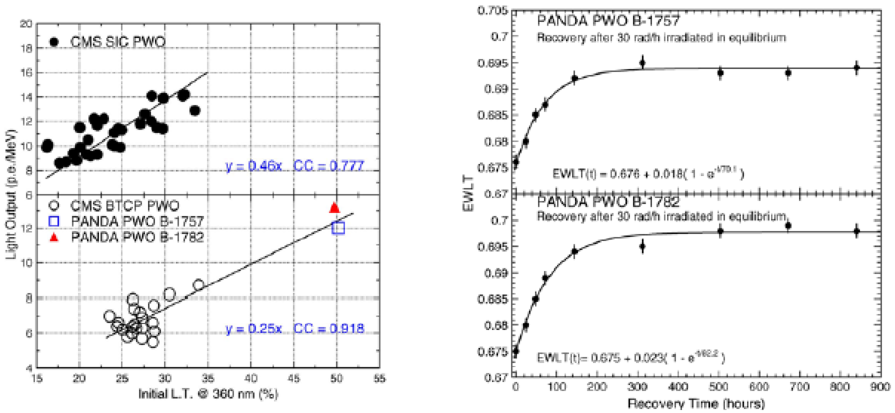


Figure 4: ***Left:*** Correlations between the initial light output (y) and the initial longitudinal transmittance (x) at 360 nm. ***Right:*** Recovery of the $PbWO_4$ emission weighted longitudinal transmittance (EWLT) irradiated at 30 rad/h. The EWLT is a direct measure of the transparency of the crystal's scintillation light. The initial EWLT values of about 70% were not reached after 900 hours recovery indicating deep color centers inside the crystal samples [16].

- Further studies: construction and testing of a prototype

Timeline and Responsibilities

Year 1= FY 2015

4. R&D Timeline and Deliverables

	Year 1 by Quarters				Year 2 by Quarters			
Deliverable	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Procure crystals from Crytur	X	X			X	X		
Produce crystals at SIC	X	X						
Crystal quality tests			X	X	X	X		
Radiation Damage studies			X	X	X	X		
Construct prototype						X	X	
Test prototype								X

5. Responsibilities

- CUA - Lead Institution. Coordination of R&D program. Procure $PbWO_4$ crystals from SIC and perform initial crystal quality measurements
- JLAB – provides facilities for radiation studies and quality measurements as needed
- BNL - Carry out radiation damage measurements (gamma ray and hadron). Study crystal readout using SiPMs
- Caltech – Perform crystal quality measurements and carry out gamma ray radiation damage studies
- IPN Orsay – procure PWO crystals from Crytur and perform initial crystal quality measurements in collaboration with University of Giessen
- Yerevan Physics Institute – Provides expertise with crystal quality measurements and comparison with other calorimeter crystal types, e.g., PbF_2 and existing $PbWO_4$

Budget

Year 1= FY 2015

6. Funding Request and Budget

Item	Year 1 ($K)	Year 2 ($K)
Procure crystals from Crytur	30	60
Purchase crystals from SIC	15	
Gamma ray radiation studies	10	10
Hadron radiation studies	10	10
Technical Support	10	15
Parts for prototype		10
Travel	8	15
Total	**83**	**120**

Table 3. Funding by task

Institution	Year 1 ($K)	Year 2 ($K)
CUA	18	30
JLAB		
BNL	15	20
Caltech	15	20
IPN Orsay	35	50
Yerevan		
Total	**83**	**120**

Table 4. Funding by Institution

Summary